National Park Service
Arctic Network Inventory and Monitoring Program

Long-term Monitoring of Vegetation Change Following Tundra Fires in Noatak National Preserve, Alaska

Arctic Network Inventory & Monitoring Program
National Park Service, Alaska Region

Charles Racine, Jennifer L. Allen, and John G. Dennis




Cover photos

Top: A lightning-caused fire in Noatak National Preserve, the Uvgoon Creek Fire #127, which started in late May of 2004 and burned 11,230 acres (NPS photo).

Inset left: Remnant fireweed (*Epilobium angustifolium*) from the Kugururok burn of 1972. Photo by Andrew Stinchfield (NPS).

Inset center, above: Tussock cotton grass (*Eriophorum vaginatum*) and shrubs (*Betula nana* and *Salix* sp.) resprouting one year after fire on the 2002 Cottonwood Bar (A520) fire in Noatak National Preserve. Photo by Brian Sorbel (NPS).

Inset center, below: Mass bloom of fireweed (*Epilobium angustifolium*) five years after the 1977 Loop fire in Noatak National Preserve. Photo by Charles Racine.

Inset right: Chuck Racine measuring vegetation changes 28 years after fire at the Uchugrak site in Noatak. Photo by Jennifer Allen (NPS).

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Key Words

Northwest Alaska, Noatak National Preserve, Tundra Wildfire, Vegetation Recovery, Sampling

Abbreviations

ARCN: Arctic Network of National Parks

I&M: Inventory and Monitoring Program, NPS

KUNG: Kungiakrok Creek site

KUGUR: Kugururok River site

NOAT: Noatak National Preserve

NOAT 1, 2, and 3: Noatak sites

NPS: National Park Service

UCHG: Uchugrak Hills site

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EXECUTIVE SUMMARY

Fire is an important driver of change at the local and landscape levels in the tundra ecosystems of Noatak National Preserve. In July 2005, with support from the National Park Service Arctic Network Inventory and Monitoring program, we relocated and remeasured fire plots established in 1981–82 at eight sites in Noatak National Preserve to evaluate the long-term (25 to 30 years) effects of tundra wildfire on vegetation and permafrost. The tussock-shrub and shrub tundra sites originally established by Racine and Dennis included one site burned in 1972, four sites burned in 1977, one site burned in 1982, and two unburned control sites. Stakes placed in the ground in 1981–82 to mark sample plots were relocated at four of the eight sites. At the remaining sites we used photos and field notes to relocate plots as close to the original as possible. Visual cover estimates were made for each species in each 1 m x 1 m plot (10 per site). Thaw depths were measured at five points in each plot. To provide for future monitoring, all sites were restaked and GPS coordinates obtained. Our experience relocating and remeasuring plots established 23 to 24 years ago indicates that these plots are valuable tools for assessing fire disturbance on tundra ecosystems.

At all four 1977 and one 1982 burned site (but not the 1972 burn) there has been an increase in vascular plant cover during the past 23 years from 1981–82 to 2005. This increase was mostly due to increases in shrub cover by as much as 65% on a shrub tundra site and 15 to 30% in tussock-shrub tundra. The shrub species involved in this increase were mostly deciduous shrubs of birch and willow. Grass and forb (mainly fireweed) cover has declined or disappeared. At two lightly burned shrub tundra sites there has been a net decrease in the number of forb species (from 21–24 species in 1981 to 14 species in 2005) during the past 24 years. Thaw depths in 2005 were similar to those measured in 1981–82 except for a site burned in 1972 and possibly again in 1984.

This analysis of change from 1981 to 2005 following tundra fire has occurred during a remarkable period of warming in the North American Arctic, with evidence for the expansion of shrubs in tundra similar to that observed at our sites. It is difficult to partition the effects of fire from the effects of climate warming because they are linked and both can result in warmer soils and associated nutrient increase. More monitoring attention needs to be given to the establishment of unburned control plots paired with burned plots to evaluate change without fire compared to change with fire.

INTRODUCTION

The National Park Service (NPS) Arctic Network Inventory and Monitoring (I&M) Program seeks to track "vital sign" resources and processes that are indicators of ecological conditions of concern to each park (Sanzone et al. 2005). The Arctic Network (ARCN) is comprised of five large land units in northwest Alaska and includes Noatak National Preserve, Kobuk Valley National Park, Bering Land Bridge National Preserve, Cape Krusenstern National Monument, and Gates of the Arctic National Park and Preserve. Fire affects all of the parks in the Arctic Network; in the past 50 years over 300,000 ha (750,000 acres) have burned within the five parks. The impacts of wildland fire in northern latitudes are well documented for boreal forests and to a lesser extent for tundra ecosystems; however, the processes and variability underlying ecosystem response are still under study (Johnstone and Chapin 2006a). Fire influences not only vegetation succession and distribution (Viereck and Schandelmeier 1980; Rupp et al. 2000; Racine et al. 2004) but also wildlife habitat (Paragi et al. 1996; Joly et al. 2003), permafrost (Dyrness 1982; Racine et al. 1983; Yoshikawa et al. 2002), nutrient cycling (Bergner et al. 2004; Smithwick et al. 2005), hydrology (Lamontagne et al. 2000), water quality (McEachern et al. 2000), and air quality (Sandberg et al. 2002). In addition, the natural fire regime (fire frequency, fire extent, and severity) and secondary fire effects are likely to respond to local and global climate changes (Rupp et al. 2000; Goetz et al. 2005).

Wildfire produces a rapid change in the physical, chemical, and biological properties of an ecosystem, changing both above- and below-ground conditions. There is immediate change in the vegetation and soils (organics, nutrients, temperatures, and microbial activity). In permafrost terrain, thawing of ice-rich permafrost, subsidence, and thermal erosion may result in complete ecosystem change. Ecosystem response begins immediately following fire, involves a great many processes, and is dependent on initial fire severity, climate, soils, topography, herbivory etc. during this period. Short-term response (from 1 to 15 years) may be different from longer-term response (15 to 30 years), particularly in forests, and recovery to prefire conditions may never occur (Johnstone and Chapin 2006b). The criteria used to measure response also vary from functional (e.g., primary production) to structural (growth forms and species composition). Both short-term and long-term monitoring of the effects of fire in the Arctic Network will provide a foundation to elucidate the complex relationship between fire and the landscape.

In the northern subarctic, lightning-caused wildfires are common in the boreal forests but less common in the arctic tundra. However, during the summer of 1977 over 400,000 ha (1 million acres) of mostly arctic tundra burned in northwest Alaska, with large fires occurring throughout the Seward Peninsula and the Noatak River watershed. After studying the effects of fire on the Seward Peninsula in 1978–79 (Racine and Racine 1979; Racine

1981), we obtained a grant from the U.S. Man and the Biosphere Program entitled "The Ecological Role of Fire in Tundra Ecosystems of the Noatak River Biosphere Reserve, Alaska" to evaluate the impacts of these fires (Racine et al. 1991). We established a base camp (67.96° N 161.84° W) near a 1977 tundra fire that burned 12,000 ha (almost 30,000 acres) along the Noatak River about 80 miles north of Kotzebue (Figs. 1 and 2) and conducted a broad range of studies, including fire history, soils, vegetation, and permafrost. Participants included four principal investigators: Charles Racine and Peter Marchand (Johnson State College), William Patterson (University of Massachusetts), and John Dennis (NPS); two graduate students (University of Massachusetts); four undergraduates (Johnson State College); and 10 Earthwatch volunteers. We monitored the Noatak base camp sites in 1981 and 1982. In addition, during our 1982 visit, we monitored fire effects at several other remote fire sites.

On July 23–30, 2005, with support from the National Park Service Inventory and Monitoring program, we (C. Racine, J. Dennis, M. Racine, J. Allen, and A. Stinchfield) relocated and remeasured the vegetation and thaw depths at three sites at our original base camp and in addition resampled three other remote sites (Table 1). The 2005 study sought to determine the feasibility and value of relocating and resampling these plots and to evaluate the long-term effects of fire on tundra ecosystems. The objectives of remeasuring these historic plots were to address the following questions:

1. How does the time since fire affect the species composition, vegetation structure, and ground cover among varying vegetation types?
2. How does the time since fire affect depth of active layer?
3. Do the vegetation and soil conditions of today suggest the presence of environmental factors in addition to post-fire recovery, such as climate change, particularly in relation to expansion of shrubs and trees (e.g., alder, willow, and spruce)?

Table 1. *Sites sampled in 1981–82 and resampled in 2005*

Site	Latitude (North)	Longitude (West)	Elev. (m)	Fire date	Prefire vegetation	Burn severity[2]
Noat 1	67.9690	161.8407	100	7/14/77	Shrub tundra	Moderate–high
Noat 2	67.9677	161.8405	100	7/14/77	Low-centered polygons	Low
Noat 3	67.9667	161.8412	100	7/14/77	Tussock-shrub	Low
Kungiakrok Ck[1]	67.9575	161.8948	100	6/21/82	Tussock-shrub	Moderate
Uchugrak Hills[1]	68.0499	161.6051	500	7/14/77	Tussock-shrub	Moderate
Kugururok R.	67.9865	161.9618	110	7/13/72	Tussock-shrub	Moderate

1. Sites with burned and unburned plots sampled.
2. Viereck fire severity classes (Viereck and Schandelmeier 1980).

METHODS

Study Area

The Noatak River watershed is one of the major river systems of arctic Alaska, draining 33,670 sq. km of the western Brooks Range just above the Arctic Circle and containing a broad range of lowland and alpine tundra, tussock tundra, shrub tundra, and treeline habitats. The study area is located near the confluence of Noatak and Kugururok rivers (Fig. 1). The vegetation in the study area is generally dominated by tussock-shrub tundra, birch-ericaceous shrub tundra, or willow shrub types. The study area is at the upriver limit of spruce along the Noatak, and scattered patches of spruce and alder are present in the area. Both spruce and alder appear to have expanded in this area during the past 50 years, as shown by Suarez et al. (1999) using age structure and by Sturm, Racine, and Tape (2001) using photos obtained along the Kugururok River less than 10 miles north of our study area.

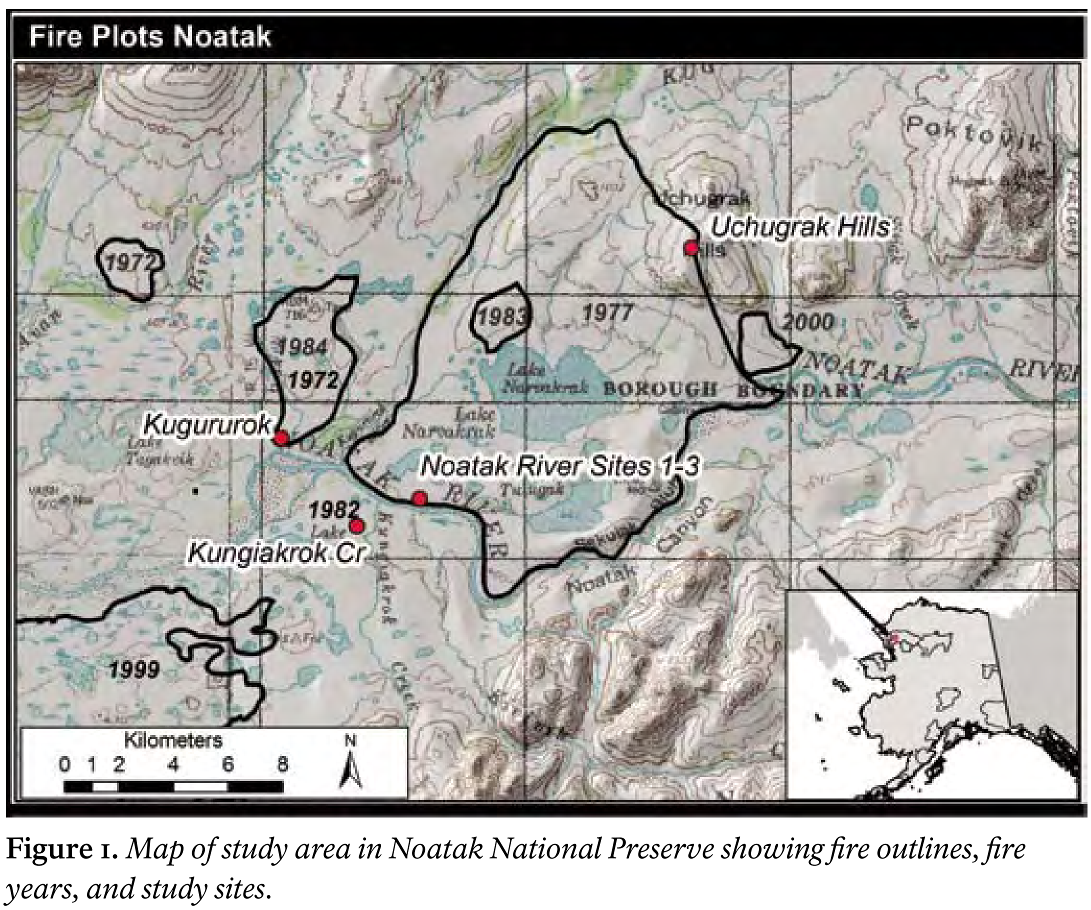

Figure 1. *Map of study area in Noatak National Preserve showing fire outlines, fire years, and study sites.*

Fire records indicate that at least 140 fires have occurred with an estimated 173,900 ha (430,000 acres) burned over the past 50 years (1956–2005) within the Noatak watershed (NPS fire database). These fires burned from 1,000 to 65,000 ha (2,500 to 160,000 acres) per year at valley elevations below 500 m (Racine et al. 1985). During the summer of 1977 in the Noatak River watershed there were at least nine fires that burned almost 70,000 ha (169,000 acres). One 1977 fire in the lowlands along the Noatak River accounted for nearly two-thirds of the area (52,355 ha [129,000 acres]). The 1977 fire sampled in this study was the second-largest Noatak fire during 1977, the Loop Fire (BLM Fire # 8657), which burned approximately 14,000 ha (35,000 acres) (Fig. 1). Fires have been historically common in this area (Racine et al. 1985), and in addition to the 1977 fire we established plots on nearby 1972 and 1982 burns.

Study Sites

Noatak River Sites

The Noatak River study area and base camp were located on the southwest edge of the 1977 Loop Fire at the northeast junction of the Noatak and Kugururok rivers (Fig. 1). This fire burned around several lakes, including the very large Lake Narvakrak, Tulugak Lake, and several unnamed lakes north of the camp. The fire burned east to the Uchugrak Hills where it was actively suppressed with hand-dug firelines. In 1981 we (C. Racine, J. Dennis, and two field assistants) occupied our camp on the Noatak River from July 18 to Aug 9. At this time we established a 265-m-long transect running north from our camp and perpendicular to the Noatak River (Table 1; Fig. 2). Along this transect, we selected three different vegetation types for intensive sampling:

- Noatak Site 1 (NOAT 1). This site is at the north end of the transect farthest from the river and appears to be a well-drained sandy beach ridge. In 1981 a 6 cm thick organic horizon was charred to a depth of 0.5 cm, suggesting moderate burn severity. Based on an unburned patch, the vegetation before the fire was shrub tundra.
- Noatak Site 2 (NOAT 2). This site is located on a gentle 1% slope dominated by low-centered polygons of generally low, round, or elliptic oblong pans or centers (5–10 m in diameter) outlined by raised hummocky ridges 1–2 m wide. The 1977 fire appears to have burned along the raised edges, leaving the centers or pans unburned or lightly burned. The rims, which were sampled, had a thick (35 cm) organic horizon above sandy mineral soil. The pans had a thin organic horizon of 4–5 cm, and the fire appears to have burned mainly the rims where shrubs were common.
- Noatak Site 3 (NOAT 3). Located on a short slope above a wet swale near the base camp, the organic horizon was 20 cm thick above silts. The vegetation here consists of *Eriophorum vaginatum* tussocks below an open canopy of *Salix glauca* willow. Burn severity was relatively low.

Figure 2. *Aerial view of camp on the Noatak River in August 1982.*

Remote Tussock-Shrub Tundra Sites

In 1982 we sampled three other burned sites all dominated by tussock-shrub tundra (Table 1; Fig. 1):

- Kungiakrok Creek (KUNG). A small 2 ha (5 acres) fire (BLM fire # 8528A) occurred on June 21, 1982, across the river from our base camp. The site was dominated by lowland tussock-shrub tundra, just beyond the base of a low ridge with scattered spruce and alder. Two sites, one burned and one unburned, were established here three weeks after the fire. The soils at the burn site had a 12 cm thick organic horizon.
- Uchugrak Hills (UCHG). A higher elevation (500 m) site on the east edge of the 1977 Loop Fire where a hand-dug fireline stopped the movement of the fire to the east. The soils are rocky, and fellfields are common along portions of this ridge; however, the less-exposed flats support tussock-shrub tundra. Sample sites were established on each side of this fireline, providing a burned and unburned site.
- Kugururok River (KUGUR). A 1972 burn just downriver from our base camp on a plateau above the confluence of the Noatak and Kugururok rivers. The burn was located using a 1973 satellite image that showed the fire scar. Fire records indicate the area burned again in 1984. We had no unburned site here but made observations on shrubs and spruce along the edge of this burn in 1982 and again in 2005. Soil pits and textural analysis showed that the soils at the site are sandy even at the tussock-tundra site sampled here. The soil organic layer was 14 cm thick, and the mineral soil was a silt-sand.

Sampling Methods

Vegetation was sampled in 1 m x 1 m plots outlined with a frame. To gain consensus, usually two people made visual estimates of percent cover for each vascular and nonvascular species in each plot. Stem density, when possible, and maximum height were measured for shrub species, and in 2005 a vertical digital photo of each plot was obtained. Ten plots of 1 m x 1 m were sampled at each site. The frequency of each species was calculated at each site by determining the percent of plots that contained the species. At KUNG and KUGUR, the plots were arranged contiguously along the west side of a 10 m long tape stretched between two rebar or stakes 10 m apart and oriented magnetic north–south. These plots were positioned and numbered beginning at the south end. At UCHG in 2005, we used a west-to-east 30 m long transect perpendicular to the fireline and established a line of ten 1 m x 1 m plots on the burned and unburned side of the fireline, with a unsampled buffer near the fireline.

Each of the three Noatak base camp sites used a staked 35 m x 12 m sample site (macroplot) that was divided into subplots and walkways for access. Within the large macroplot, two rows (designated A and B) were established, consisting of five areas of 4 m x 5 m. We randomly selected one of the four corners of each 4 m x 5 m area to establish a 1 m x 1 m plot to sample. These plots are named for example "3A1SW" for Site 3, the first 4 m x 5 m plot in row A, and the 1 m x 1 m plot in the southwest corner of the 4 m x 5 m area. Because short wooden stakes (lathe, spruce, or willow) had been placed at two to four corners of each of the ten 1 m x 1 m plots when they were established in 1981, and most of these survived until 2005, each of the ten 1 m x 1 m plots were measured in 1981, 1982, and 2005.

We measured thaw depths in 1981, 1982, and 2005 with a steel probe pushed to resistance in the four corners and center of each 1 m x 1 m plot (five thaw depth probes per plot) for a total of 50 measurements per site.

Data Analysis and Presentation

We present the results visually and quantitatively by first presenting repeat photos taken of the sites in 1981–82 and again in 2005. Then we show in tables both frequency and cover data for each species. For plots sampled in both 1981 and 1982 (at NOAT 1, 2, and 3 sites), the difference in species cover between these two years was very small and within the error of cover estimates (about 5%), so we present a single value to represent the two years. Species detected only once in a plot were not included in the results. Tables and graphs emphasize plant functional types (Chapin et al. 1996) based on their growth form (i.e., graminoids, forbs, evergreen shrubs, deciduous shrubs, lichens, mosses, etc.) and response to disturbance. This approach has been used extensively in analyzing vegetation change in tussock tundra in plots experimentally warmed or fertilized at Toolik Lake (Shaver et al. 2001).

We compared the overall difference in average vegetation cover by sample year for the burned (six sites, n = 60 plots) and unburned sites (two sites, n = 20 plots) using a Kruskal-Wallis one-way ANOVA. We used a nonparametric test because of unequal variances and non-normal distributions. Individual sample plots (ten per site) were used for variance. We used SPSS statistical package (Version 13.0; SPSS Inc. 2004) for all analyses. Significance level of statistical tests was set at $P < 0.05$.

RESULTS

Noatak Sites

The three Noatak River base camp sites are described first. Table 2 summarizes the vegetation data for all three of these sites and compares species frequency and cover in 1981 and 2005. All three of these sites near the river occur in a geologically complex and plant species-rich area and are quite distinct in terms of soils and vegetation from the three other more typical tussock-shrub tundra sites. In 1981–82 we sampled almost 60 species of vascular plants in our plots at NOAT 1, 2, and 3 combined (Table 2). By 2005 the number of species at these three sites had decreased significantly, suggesting that fire had originally created habitat for some forb species.

Noatak Site 1 (NOAT 1)

This shrub tundra site is located on a slightly raised sandy ridge 225 m north of our 1981–82 base camp on the Noatak River. In 1981 there was a 1 cm thick layer of charred material as well as abundant charred woody litter (up to 292 gm/m^2), suggesting a moderate to

Figure 3a. *Noatak River Site 1 in July 1981. Visually dominated by grasses four years after fire. Dwarf shrub tundra before fire.*

Figure 3b. *Noatak River Site 1 in July 2005. Note absence of bluejoint grass and abundance of shrub birch.*

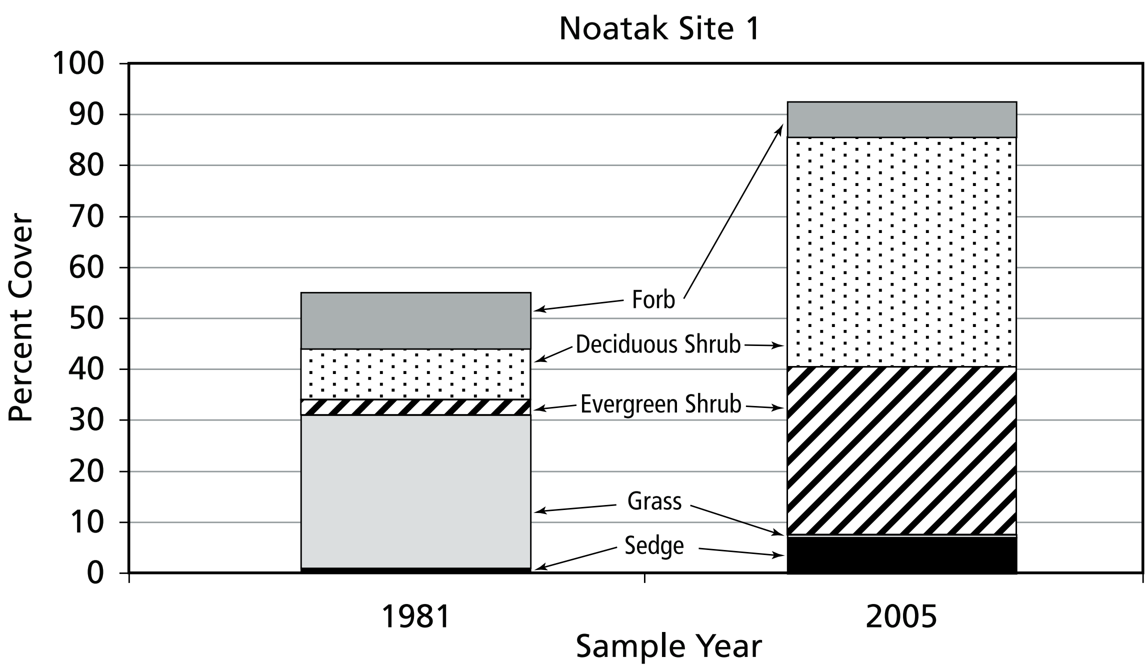

Figure 4. *Noatak River Site 1 cover by growth forms in 1981 and 2005. Note loss of grass cover and dramatic increase in both evergreen and deciduous dwarf shrubs.*

severe burn in 1977. When the vegetation was first sampled four and five years after the 1977 tundra fire, the vegetation was visually dominated by tall dead and live grass (mainly *Calamagrostis canadensis*) (Figs. 3a and 4). Grass cover was 30% and shrub cover was 14%, primarily willow (*Salix glauca*), dwarf birch (*Betula nana*), Labrador tea (*Ledum palustre*), and blueberry (*Vaccinium uliginosum*). *Ceratodon purpureus* moss cover was 10%, and forb cover (mainly fireweed) was about 11%. There were also at least 11 other forb species present, including *Oxytropis* sp. and *Saussurea angustifolia* (Table 2).

By 2005, 28 years after fire and 23 years since last sampled, grass cover had virtually disappeared and shrub cover had increased from 14% to 79% in 2005 (Figs. 3b and 4). Of the four shrubs present in 1981, Labrador tea made the largest cover increase (30%), followed by birch (20%). Willow and blueberry had only increased by about 8% and 5% respectively (Table 2).

Table 2. *Frequency (Freq) and average cover (C) for species sampled at Noatak River Sites 1, 2, and 3 in 1981 and 2005.*

Vegetation type and species	Noatak Site 1				Noatak Site 2				Noatak Site 3			
	1981		2005		1981		2005		1981		2005	
	Freq (%)	C (%)	Freq (%)	C (%)	Freq (%)	C (%)	Freq (%)	C (%)	Freq (%)	C (%)	Freq (%)	C (%)
GRAMINOIDS												
Sedge												
Carex aquatilis	0	0	0	0	70	0.5	10	0.1	10	1	0	0
Carex bigelowii	40	0.5	90	1.5	90	1	100	7	100	2	80	4
Carex membranacea	0	0	0	0	50	1	20	2	0	0	0	0
Eriophorum angustifolium	0	0	0	0	0	0	10	0.5	60	1	90	0.7
Eriophorum vaginatum	0	0	100	5	90	1	50	5	100	20	90	27
Luzula arctica	40	0.5	30	0.5	70	1	20	0.5	0	0	0	0
Sedge cover		1		7		4.5		14		23		32
Grass												
Arctagrostis latifolia	10	0.5	0	0	90	1	10	0.1	80	1	0	0
Calamagrostis canadensis	100	29	0	0	30	0.5	10	0.1	10	1	0	0
Hierochloe alpina	0	0	40	0.2	0	0	0	0	0	0	0	0
Poa arctica	40	0.5	30	0.2	90	5	10	0.1	80	1	10	0.1
Grass cover		30		0.5		6		0.5		3		0
SHRUBS												
Deciduous shrubs												
Arctostaphylos alpina	10	0.5	10	0.1	90	1	0	0	30	0.5	20	3
Betula nana	50	3	100	24	50	1	20	0.5	0	0	0	0
Dryas integrifolia	0	0	20	0.5	70	2	100	6	60	5	60	2.5
Potentilla fruticosa	0	0	10	0.5	50	1.5	50	1	50	1	50	2
Salix arctica	0	0	0	0	70	2	100	6	10	1	30	1
Salix glauca	70	4	90	12	0	0	0	0	50	16	80	20
Salix lanata	0	0	0	0	30	1	10	1	0	0	30	3.5
Salix reticulata	20	0.2	20	0.1	90	3	70	6	80	2	90	11
Vaccinium uliginosum	80	3	70	8	90	2	90	14	20	0.1	20	0.5
Deciduous cover		10		45		13		35		25		43
Evergreen shrubs												
Ledum palustre	70	3	100	33	10	0.1	20	0.5	0	0	0	0

(continued on next page)

Rhododendron lapponicum	0	0	20	0.2	0	0	40	0.5	0	0	0	0
Evergreen cover		3		33		0.5		1		0		0
TREES												
Picea glauca	0	0	10	1	0	0	0	0	0	0	0	0
FORBS												
Aconitum delphinifolium	90	1	80	1	0	0	0	0	0	0	0	0
Androsace chamaejasme	0	0	0	0	10	0.1	10	0.1	0	0	0	0
Anemone richardsonii	0	0	80	0.5	0	0	0	0	90	1.5	80	1
Armeria maritima	20	0.5	20	0.2	0	0	0	0	0	0	0	0
Artemisia tilesii	0	0	0	0	10	0.1	0	0	0	0	0	0
Astragalus alpinus	0	0	0	0	0	0	20	0.2	10	0	10	0
Cardamine sp.	0	0	0	0	100	1	0	0	90	1	0	0
Cerastium beringiana	0	0	0	0	0	0	0	0	0	.5	0	0
Draba sp.	0	0	0	0	60	0.5	0	0	20	0.1	0	0
Epilobium angustifolium	90	2	40	0.5	100	1	10	0.1	60	0.5	0	0
Equisetum scirpoides	0	0	0	0	40	0.2	10	0.5	60	1	40	1.2
Equisetum arvense	30	0.5	50	1	100	1	80	6	100	3	90	12
Gentiana propinqua	0	0	0	0	30	0.2	0	0	20	0.1	10	0.1
Gentiana prostrata	0	0	0	0	20	0.1	0	0	0	0	0	0
Lagotis glauca	0	0	20	0.1	0	0	0	0	20	0.1	0	0
Lupinus arcticus	0	0	0	0	0	0	0	0	10	0.1	0	0
Melandrium apetalum	0	0	0	0	40	0.5	0	0	0	0	0	0
Minuartia rossii	0	0	0	0	30	0.5	0	0	10	0.1	0	0
Oxytropis maydelliana	90	3	80	1	0	0	0	0	0	0	0	0
Papaver macunii	20	0.5	10	0.1	10	0.1	0	0	10	0	0	0
Parnassia kotzebuei	0	0	0	0	10	0.1	10	0.1	0	0	40	0.2
Pedicularis kenaii	20	0.5	60	0.5	30	0.1	40	0.3	20	0.1	30	0.2
Polemonium acutiflorum	0	0	0	0	0	0	10	0.1	0	0	0	0
Polygonum bistorta	60	0.5	30	0.2	0	0	10	0.3	0	0	10	.1
Polygonum viviparum	0	0	10	0.1	50	0.5	40	0.4	20	0.1	0	0
Pyrola secunda	0	0	0	0	30	0.1	0	0	50	1	30	.5
Rumex arctica	10	0.1	0	0	0	0	10	0.1	0	0	0	0
Saussurea angustifolia	100	2.5	90	1.5	10	0.5	0	0	70	0.5	10	.1
Saxifraga hieracifolia	0	0	0	0	10	0.1	0	0	60	0.5	0	0
Saxifraga hirculus	0	0	0	0	50	0.5	40	0.2	80	0.5	50	1
Saxifraga punctatum	60	0.5	30	0.2	0	0	0	0	0	0	0	0
Senecio residifolius	0	0	0	0	0	0	20	0.2	30	0.4	20	0.1
Stellaria laeta	10	0.5	0	0	10	0.1	0	0	20	0.1	0	0
Thalictrum alpinum	0	0	10	0.1	80	0.5	60	0.5	70	0.1	30	0.2
Toffieldia coccinea	0	0	40	0.3	0	0	30	0.5	0	0	0	0
Valeriana capitata	0	0	0	0	0	0	0	0	10	0.1	0	0
Forb cover		11		7		6		9		11		17
BRYOPHYTES												
Marchantia polymorpha	30	0.5	0	0	70	1	0	0	70	3	20	0.4
Ceratodon purpurea	100	9	0	0	100	20	0	0	100	15	0	0
Tomenthypnum nitens	0	0	0	0	0	0	70	7	0	0	70	8
Drepanocladus sp.	0	0	0	0	0	0	50	3	0	0	20	0.5
Aulacomnium sp.	0	0	70	6	0	0	0	0	0	0	10	0.5
Hylocomium sp.	0	0	0	0	0	0	0	0	0	0	60	6
Polytrichum sp.	100	1	60	15	0	0	0	0	0	0	0	0
Bryophyte cover		11		21		21		10		18		15

In addition to shrub cover changes, the average shrub height increased at NOAT 1 (Table 3). The tallest shrub sampled in the ten plots in 2005 was birch (60 cm). From 1982 to 2005, willow showed the greatest increase in average maximum height (15 to 31 cm), followed by birch, then Labrador tea (Table 3). Therefore, although Labrador tea had the largest increase in cover, we estimate that shrub birch and willow had a greater increase in biomass because of the combined increase in height and cover.

Table 3. *Individual 1 m x 1 m plot cover (%) and maximum height (cm) comparisons for three shrub species at Noatak Site 1 in 1982 and 2005 and difference from 1982 to 2005 (Δ).*

	Betula nana						*Salix glauca*						*Ledum palustre*					
	1982		2005		Δ		1982		2005		Δ		1982		2005		Δ	
Plot	C (%)	max ht (cm)	C (%)	max ht (cm)	C (%)	max ht (cm)	C (%)	max ht (cm)	C (%)	max ht (cm)	C (%)	max ht (cm)	C (%)	max ht (cm)	C (%)	max ht (cm)	C (%)	max ht (cm)
A1NW	0	-	5	22	5	22	12	42	20	43	8	1	3	14	30	17	27	3
A2NE	0	-	7	17	7	17	11	33	10	32	-1	-1	3	16	45	17	42	1
A3NW	0.5	12	12	36	11	24	5	3	15	37	10	34	3	12	55	14	52	2
A4SW	15	38	55	60	40	22	0	0	5	5	5	5	4	20	15	17	11	-3
A5SE	12	40	35	37	23	-3	0.5	3	8	40	7.5	37	16	18	35	17	19	-1
B1NW	1	19	30	35	29	16	0	-	5	20	5	20	0	-	35	10	35	10
B2SW	0	-	1	5	1	5	0	-	25	35	22	35	4	16	40	16	36	0
B3SE	15	45	60	42	45	-3	10	6	5	38	-5	32	5	18	40	25	35	7
B4SW	0	-	8	16	8	16	8	5	23	31	13	26	0	-	15	15	15	15
B5NE	2	28	25	45	23	17	0	-	0	-	0	-	0	-	20	17	20	17
Average	5	30	24	32	19	13	5	15	12	31	7	21	4	16	33	17	29	5

The number of forb species at Site 1 has increased slightly from 12 to 14 species during the past 23 years, while the average cover decreased (Table 2). Most of the 12 forb species present in 1981 were still present in 2005, although fireweed frequency had decreased from 90% to 30% (Table 2). In addition a single spruce seedling, 16 cm tall, was sampled in one of these plots in 2005. No spruce seedlings were found in any of the 1 m x 1 m plots during 1981 and 1982 sampling.

The average thaw depth at Site 1 was 91 (SD 6.9) when it was first measured on August 3, 1981 (Table 4). Thaw depths in late July 2005 averaged about 80 (SD 6.7). These depths are typical of a well-drained Arctic Brown soil and show little increased thawing due to the 1977 fire.

Table 4. *Average thaw depths at eight sites measured on dates in 1981–82 and 2005 (standard deviation) and difference from 1982 to 2005 (Δ). Thaw depths are based on 50 probes per site (five in each 1 m x 1 m plot), nm = not measured*

Site	1981		1982		2005		Δ
NOAT 1	91 (6.9)	Aug 3	79 (6.8)	Jul 20	79 (6.7)	Jul 26	0
NOAT 2	nm		60 (15)	Jul 20	62 (15)	Jul 27	+2
NOAT 3	52 (11)	Jul 30	50.5 (9)	Jul 20	48 (7.5)	Jul 26	−1.5
Uchugrak							
Burned	nm		49 (7)	Jul 19	48 (14)	Jul 28	−1
Unburned	nm		35 (6.7)	Jul 19	49 (12)	Jul 28	+14
Kungiakrok							
Burned	nm		38 (7)	Jul 30	41 (14)	Jul 27	+3
Unburned	nm		27 (5.4)	Jul 30	33 (13)	Jul 27	+6
Kugururok	nm		30 (8)	Jul 14	50 (11)	Jul 29	+20

Noatak Site 2 (NOAT 2)

This site is located on a gentle 1% slope dominated by low-centered polygons of generally low, round, or elliptic oblong pans or centers (5–10 m in diameter), outlined by raised hummocky ridges 1–2 m wide (Figs. 5a and b). There is frequently a contraction crack running along the crest of these rims. These rims appear to be fairly well drained and before the fire (based on a nearby unburned area) were dominated by a mixture of shrubs (birch, willow, blueberry, and *Dryas*) and the sedge *Carex bigelowii*. The unburned centers of pans were dominated by a species-rich wet meadow of low-growing cottongrass (*Eriophorum vaginatum*), several species of *Carex*, *Juncus castaneus,* and abundant *Dryas integrifolia*.

The 1977 fire appears to have burned lightly along the raised ridges, leaving the centers of pans unburned or only very lightly burned. The raised rims bordering the pans were sampled in both 1981–82 and again in 2005. Four years after fire the rims were dominated by about equal cover of graminoids (mainly *Poa* sp.) and shrubs (*Salix reticulata* and *Dryas*).

Total vascular vegetation cover increased from 30% in 1981 to 60% in 2005 (Fig. 6). Deciduous shrub cover at NOAT 2 has increased in the past 23 years from 13% to 35%, mainly due to the expansion of the prostrate shrubs *Dryas integrifolia*, *Salix arctica, S. reticulata*, and the taller *Vaccinium uliginosum*. Grass cover decreased from 6% in 1981 to 1% in 2005, while sedge cover increased from 5% to 14% (Fig. 6).

In 1981 there were 21 herbaceous forb species sampled (Table 2). By 2005, 13 of these species were not present, including *Gentiana propinqua* and *G. prostrata,* both small annual herbs described by Marchand (2001) as fire dependent. There were three new forb species in 2005 not present in 1981, resulting in a net loss of ten species. Fireweed was present in only one plot in 2005 compared with all ten plots in 1981. Yet forb cover has increased slightly due to the expansion of horsetail (*Equisetum arvense*).

Thaw depths at Site 2 showed little change between 1982 and 2005 (60–62 cm) (Table 4).

Figure 5a. *Noatak River Site 2 in July 1981, four years after fire. Low-centered polygons with burned rims.*

Figure 5b. *Noatak River Site 2 in July 2005, 28 years after fire. Note the* Rumex arctica *spike also visible in Figure 5a and enlarged shrub clump just to left of people in both photos and tall dead grass in 1981, absent in 2005.*

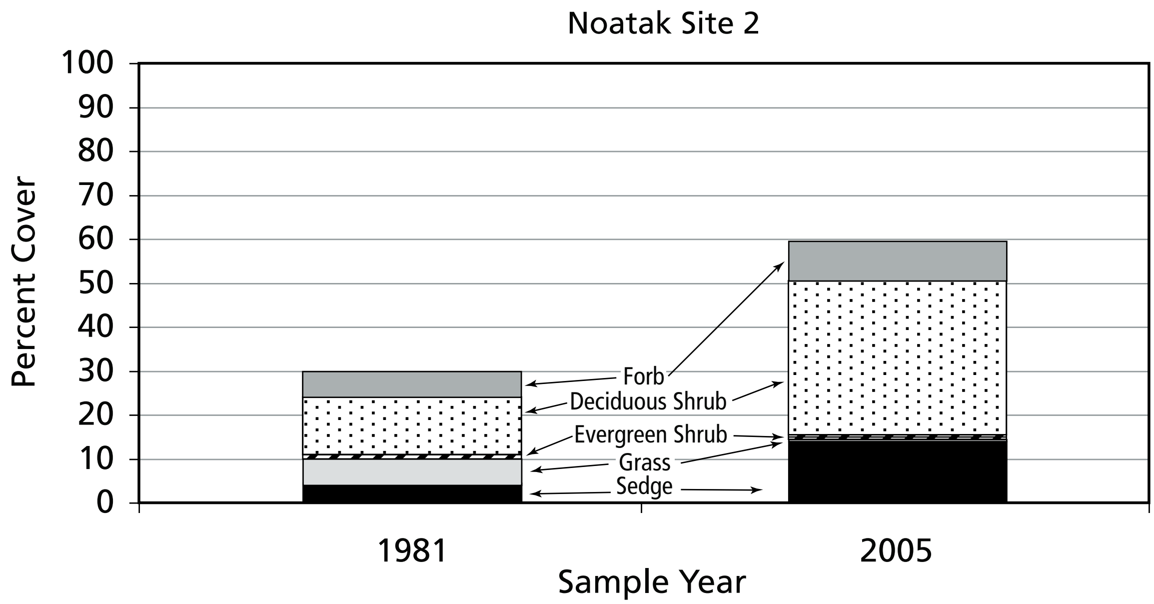

Figure 6. *Noatak River Site 2 cover by growth forms in 1981 and 2005, showing an increase in deciduous shrubs and sedge cover.*

Noatak Site 3 (NOAT 3)

Tussock-shrub vegetation dominated this poorly drained short 5% slope that rises from a wet swale to the higher ground where Sites 1 and 2 are located (Fig. 7). Soils are poorly drained, and thaw depths at the end of July in 1981, 1982, and 2005 were between 52 and 48 cm, respectively (Table 4). Fire severity here was low.

Figure 7. *Noatak River Site 3 tussock-willow in July 2005, 28 years after fire.*

In 1981, 1982, and 2005 the site had an open overstory of 0.5 to 1 m tall willow (*Salix glauca*) (Fig. 7) with a ground cover of *Eriophorum vaginatum* tussocks, *Equisetum arvense*, *Dryas integrifolia*, and *Salix reticulata*. The almost complete absence here of the shrub species *Betula nana* and *Ledum palustre*, which are characteristic of tussock-shrub tundra, makes this a very atypical site.

The dominant vegetation changes over the past 23 years are due to an increase in deciduous shrubs and a slight decrease in grass and forb cover (Table 2 and Fig. 8). Total vascular cover has increased from 61% in 1981 to 92% in 2005 (Fig. 8). This change in cover is accounted for mainly by four species: *Eriophorum vaginatum* (20% in 1981 to 27% in 2005), *Equisetum arvense* (3% to 12%), and the deciduous shrubs *Salix glauca* (13% to 20%) and *S. reticulata* (2% to 11%). Of the three Noatak sites in 1981, this site contained the largest number of forb species (24) in 1981 (Table 2). By 2005 the number of forb species had decreased to 13, similar to the forb diversity at the other two NOAT sites. Grasses were never very important at this site.

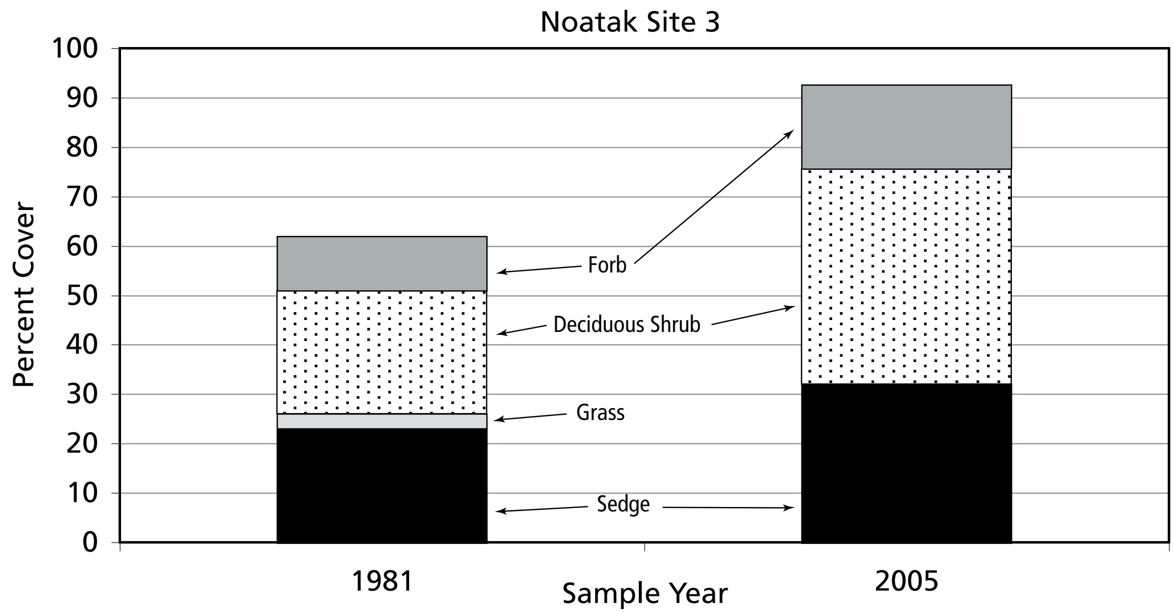

Figure 8. *Noatak River Site 3 cover by growth forms in 1981 and 2005, showing an increase in deciduous shrubs and slight decrease in grass cover.*

Kungiakrok Creek

A small 2 ha (5 acres) tundra fire burned here on June 21, 1982 (BLM fire #8528A). We noticed the burn while flying to our camp across the river in 1982 and made two visits to the site on July 11 and on July 29, 1982. On July 27, 2005, we were able to relocate the rebar stakes installed in 1982 that marked the ends of the 10 m x 1 m sample on the burn. Although we were not able to relocate the 1982 unburned sample plot, we were able to use a sketch map in the 1982 field notebook to select an unburned comparison plot in 2005.

Kungiakrok Creek: Burned (KUNG-B)

In 1982 we monitored early recovery 20 and 38 days following the June 21 fire (Fig. 9a). On July 11, 1982, 20 days after the fire, it was apparent that tussock leaf growth was already well underway (Fig. 9a). Fire had removed about 5–10 cm of the 12–14 cm thick organic horizon between tussocks. Microtopographic relief between tussock bases and tops was 30–35 cm in the burned site compared with 15–20 cm in the unburned site, a difference that indicates that about 10 cm of the organic horizon in the intertussock spaces had burned away. Standing water was also present at the bottom of the intertussock spaces on the burned area.

Figure 9a. *Kungiakrok Creek tussock-shrub tundra on July 11, 1982, three weeks after a June 21, 1982, fire. Note white* Sphagnum *moss mats exposed by fire.*

On July 11, vascular plant cover was about 30%, with sedges comprising 29% and re-sprouting shrubs only 1–2% (birch, willow, and blueberry). *Eriophorum vaginatum* leaves comprised most of the vascular plant cover with leaves about 15 cm long. Very small amounts of the grasses (*Calamagrostis canadensis* and *Arctagrostis latifolia*) were already apparent. By July 29, 38 days after the fire, vascular cover had increased to 44% with shrubs making the greatest increase from 2% to 9%. Sedge cover increased from 29% to 31% during the 18-day period between July 11 and July 29 (Table 5). Resprouting Labrador tea and lingonberry (*Vaccinium vitis-idaea)* were apparent for the first time, and monocot seedlings (*Eriophorum vaginatum*), presumably germinating from a buried seed source, averaged almost 30 plants/m^2. Also *E. vaginatum* flower buds had developed by this time.

In 2005, 23 years after the fire, the total vascular cover was 98%, an increase of 50% since July 29, 1982 (Figs. 9b and 10). The increase in vascular cover resulted primarily from an increase in sedge cover (*E. vaginatum* and *Carex bigelowii*) from 36% cover in 1982 to 70% cover in 2005 (Table 5). Tussock density was relatively high (4.2/m^2), accounting for the high sedge cover, and there was no evidence that the tussock density increased from 1982 to 2005. Shrub cover also increased from about 9% five weeks after the fire to nearly 27% by 2005 (Fig. 10), including birch (10%), Labrador tea (10%), and willow (*Salix pulchra*) (6%). The *Sphagnum* moss polsters visible in Fig. 9a after the fire in 1982 showed no sign of recovery in 2005 and were most likely killed by the fire.

Thaw depths at the burned site did not change significantly during the past 23 years, remaining at about 40 cm (Table 4), about 10 cm deeper than at the unburned comparison site.

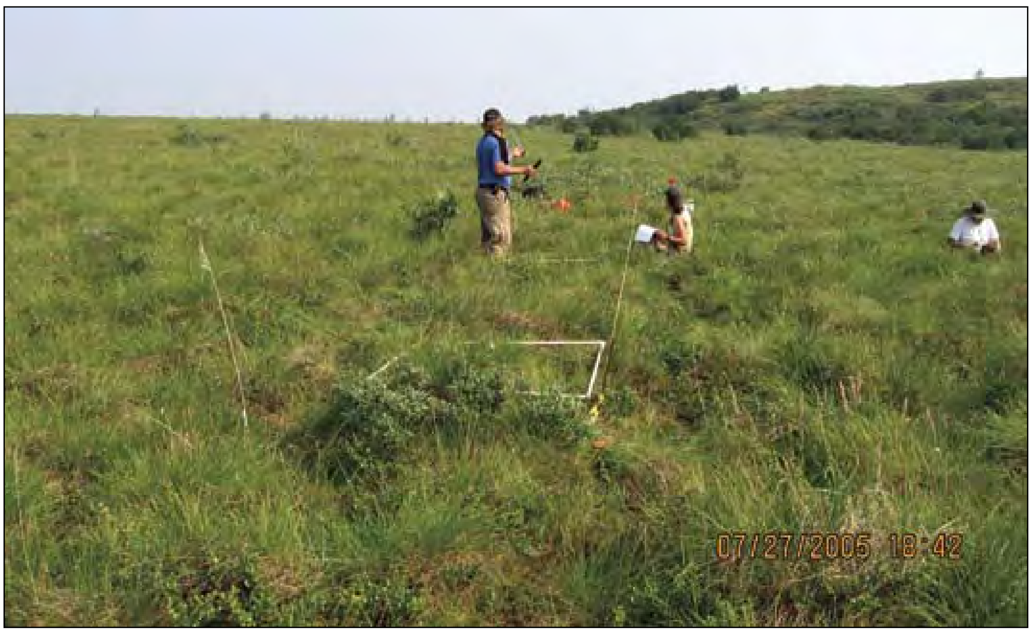

Figure 9b. *Same Kungiakrok Creek site as shown in Figure 9a on July 27, 2005, 23 years after fire.*

Kungiakrok Creek: Unburned (KUNG-U)

On the unburned plot, the total vascular cover increased slightly from 1982 (77%) to 2005 (86%), with an increase in shrub cover from 30 to 53% and a decrease in sedge cover from 48 to 33% (Fig. 11 and Table 5). In 1982 Labrador tea was the dominant shrub (18% cover), followed by birch (7%), willow (2%), and blueberry (0.5%) (Table 5). In 2005 Labrador tea was still the dominant shrub (26%), followed by birch (18%).

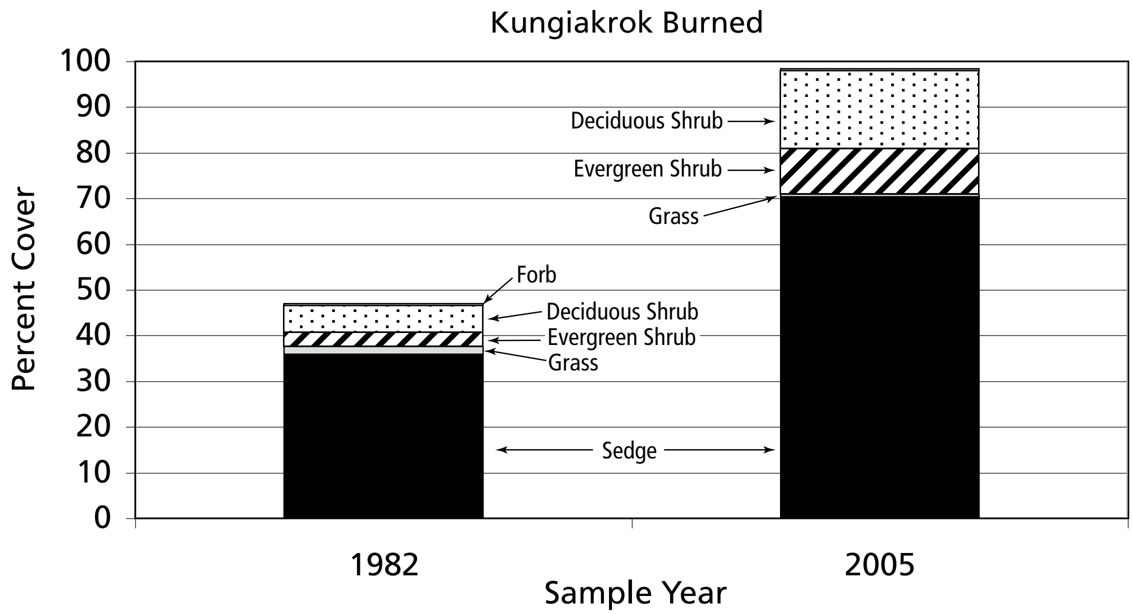

Figure 10. *Average percent cover by growth form for the tussock-shrub tundra Kungiakrok burn site sampled three weeks after the fire in 1982 (left) and 23 years after the fire in 2005 (right).*

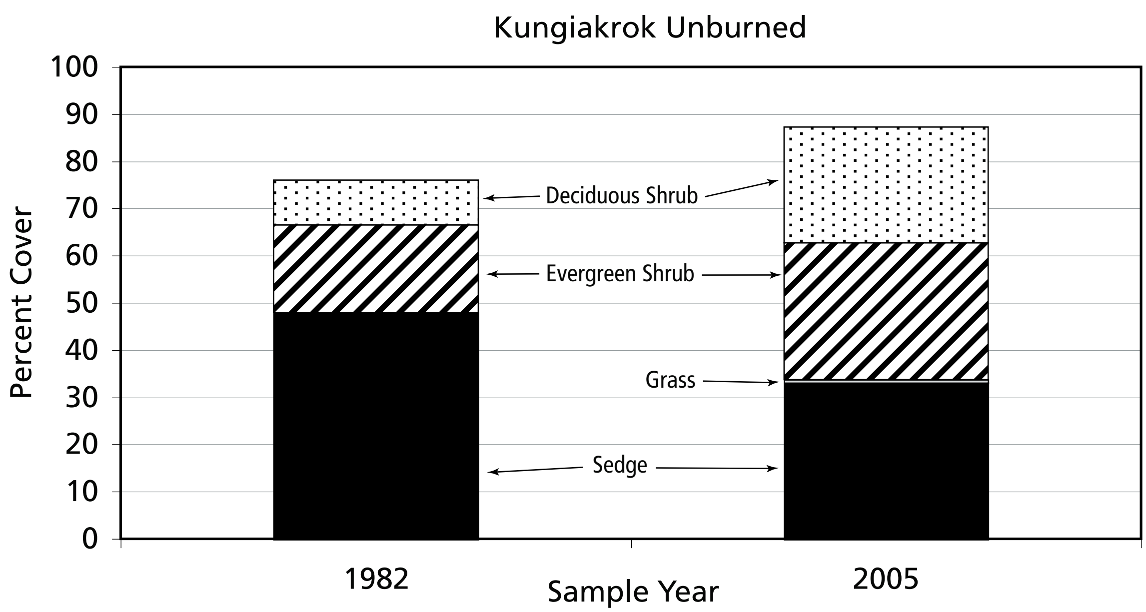

Figure 11. *Average percent cover by growth forms on an unburned control site at Kungiakrok Creek in 1982 (left) and 2005 (right).*

Table 5. *Frequency (Freq) and average cover (C) for species sampled at Kungiakrok burned and unburned sites in 1982 and 2005.*

	Kungiakrok unburned				Kungiakrok burned					
	7/11/1982		7/27/2005		7/11/1982		7/29/1982		7/27/2005	
	Freq (%)	Av C (%)	Freq (%)	Av C (%)	Freq (%)	Av C (%)	Freq (%)	Av C (%)	Freq (%)	Av C (%)
GRAMINOIDS										
Sedge										
Eriophorum vaginatum	100	39	100	25	100	25	100	25	100	64
Carex bigelowii	100	9	100	8	100	2.8	100	11	100	7
Sedge cover		48		33		28		36		71
Grass										
Arctagrostis latifolia	0	0	10	0.5	20	0.2	20	0.2	20	0.1
Calamagrostis sp.	0	0	50	0.3	100	0.8	100	1.5	40	0.3
Grass cover		0		0.8		1		1.7		0.4
SHRUBS										
Deciduous shrubs										
Betula nana	100	7	100	18	80	0.8	80	3	80	10
Salix glauca	0	0	0	0	0	0	0	0	20	1
Salix pulchra	70	2	90	6	30	0.5	60	3	60	6
Vaccinium uliginosum	30	0.5	20	0.5	20	0.2	30	0.2	10	0.2
Deciduous shrub cover		9.5		24.5		1.5		6		17
Evergreen shrubs										
Ledum palustre	100	18	100	26	0	0	80	3	100	10
Vaccinium vitis-idaea	10	0.5	30	3	0	0	0	0	0	0
Evergreen shrub cover		18.5		29		0		3		10
FORBS										
Epilobium angustifolium	0	0	0	0	10	0.1	20	0.3	20	0.5
BRYOPHYTES										
Sphagnum sp.	0	0	60	6	40	1.5	40	1.5	50	1
Feather moss	50	3.5	80	2	90	7.2	80	5.5	50	1
Bryophyte cover		3.5		8		8.7		7		2
LICHENS										
Peltigera	20	0.2	10	0.1	0	0	0	0	20	0.2

Uchugrak Hills

This tussock-shrub tundra site is located on the east edge of the 1977 fire in a flat saddle at an elevation of 500 m along a ridge. During the 1977 fire a hand-dug north-south fireline about 20 cm wide and 20 cm deep was constructed, which successfully stopped the fire (Fig. 12). This fireline provided us a burned and unburned landscape to the west and east, respectively, of the fireline. The soils in this saddle are rocky, and although permafrost is common here, the fireline has not caused any thermokarst. Thaw depths in the fireline trench were about 40 cm in late July 1982 and 30–70 cm in late July 2005.

In July 2005 we relocated the fireline from a helicopter, and although we were unable to locate the stakes from 1982, we were able to use the fireline to establish a sample site near the original one using 1982 photos and descriptions (Figs. 12, 13a and b).

Uchugrak: Burned (UCHG-B)

In 1982, five years after fire, total vascular cover on the burn was 43% (Fig. 14). This cover had increased to 83% by 2005 so that vascular cover had almost doubled on the burn during the past 23 years. In 1982 the burned site was dominated by sedges (*Eriophorum vaginatum* and *Carex bigelowii*), with a small percent of cover contributed by shrubs (7%), fireweed (4%), and grasses (1%) (Table 6). By 2005, sedge cover had increased by only 5%, but shrub cover had made a large increase to 40% (Fig. 14). Willow (*Salix pulchra*) and birch accounted for most of the shrub cover in 2005, and the forb *Petasites frigidus* was abundant (Table 6).

Uchugrak: Unburned (UCHG-U)

On the unburned side of the fireline, the total vascular plant cover in both 1982 and 2005 was about 70%, with most of the cover (45–50%) contributed by shrubs (Fig. 15). Birch was the dominant shrub in both 1982 and 2005, and willow, blueberry, Labrador tea, and lingonberry (*Vaccinium vitis-idaea*) also contributed to the shrub cover (Table 6).

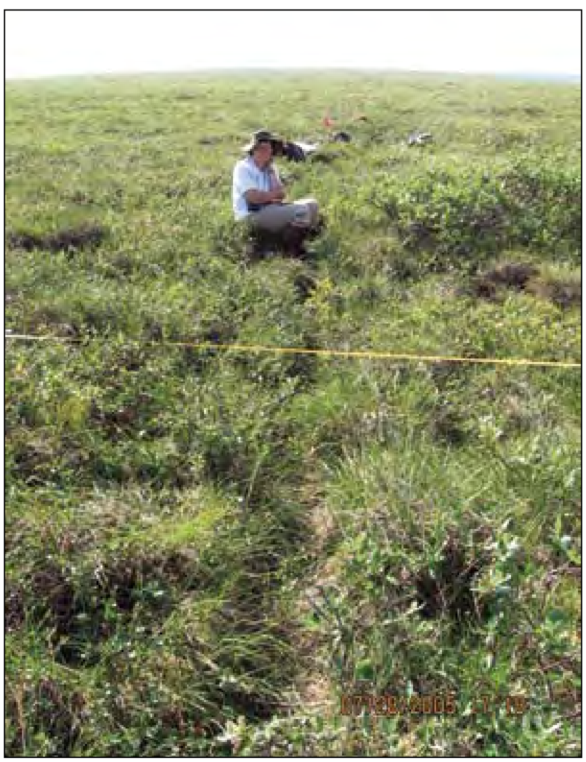

Figure 12. *Hand-dug 1977 fireline on Uchugrak Hills, still visible in July 2005 separating burned (left) and unburned (right) side.*

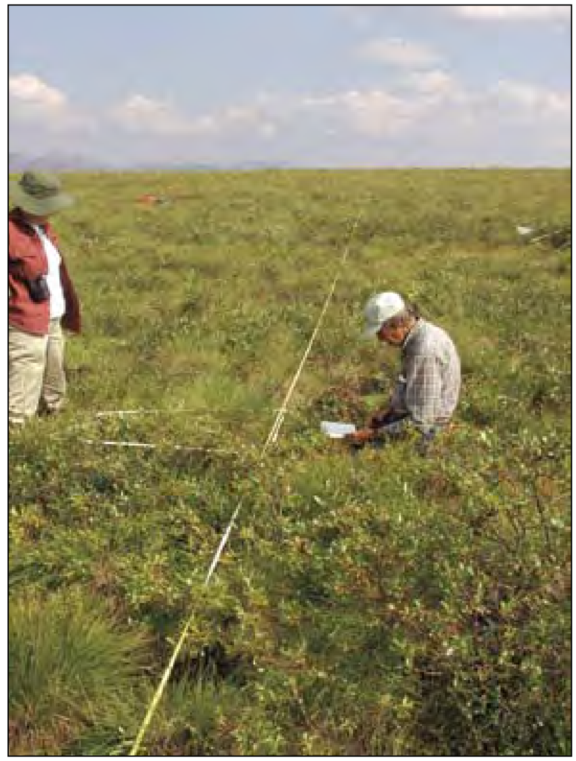

Figure 13a and b. *Uchugrak Hills burned montane tussock-shrub tundra in July 1982, five years after fire in 1977 (left), and in 2005 (right). Note the increase in willow (*Salix pulchra*) and dwarf birch (*Betula nana*).*

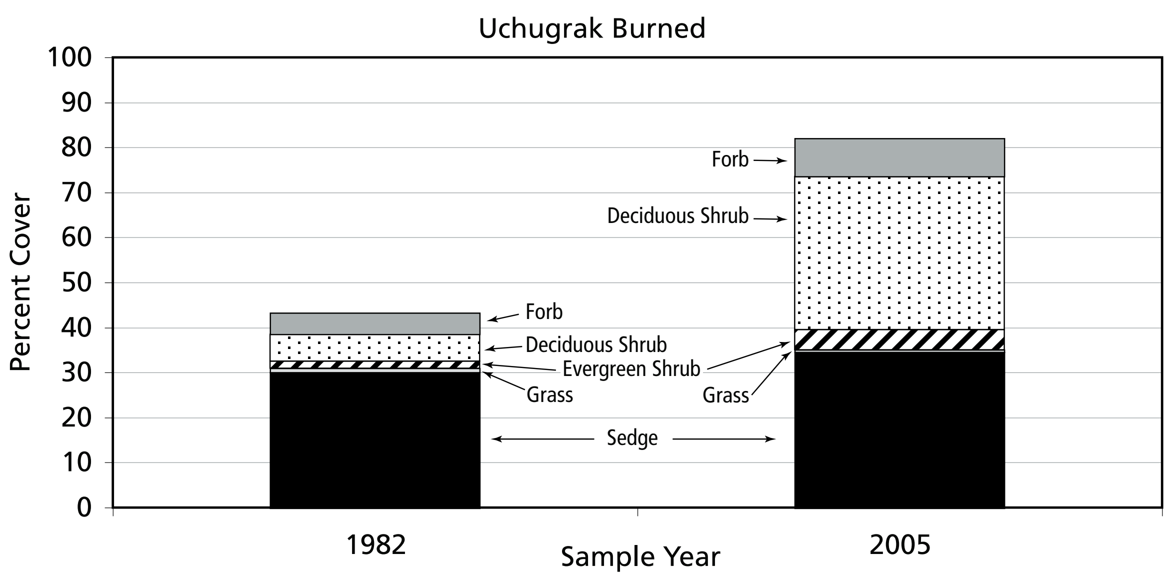

Figure 14. *Average percent cover of growth forms at the 1977 burned Uchugrak Hills tussock-shrub tundra site in 1982 (left) and 2005 (right).*

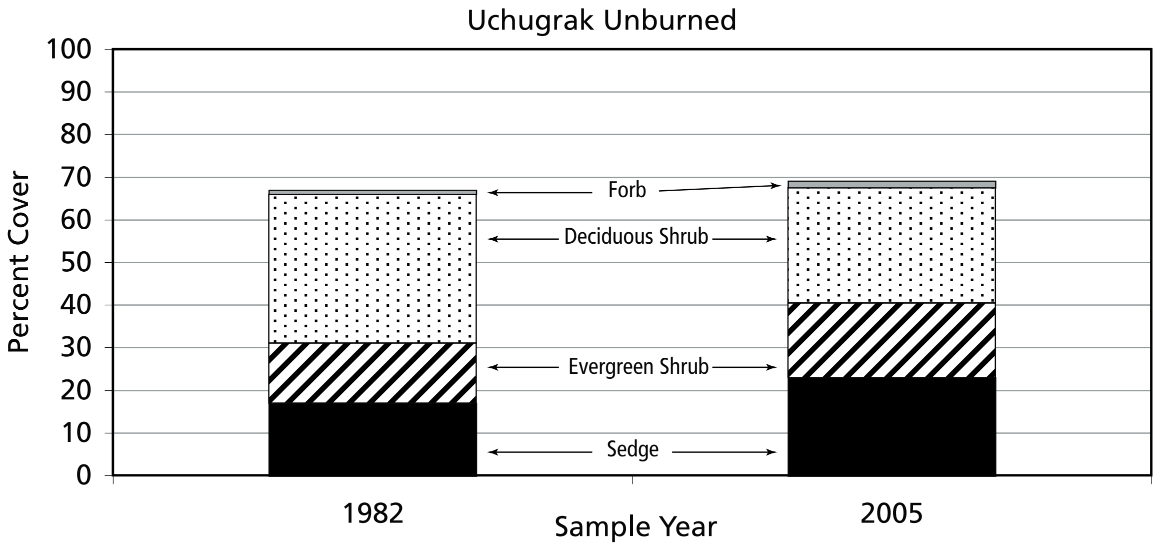

Figure 15. *Average percent cover of growth forms on unburned control side of fireline in Uchugrak Hills 1982 (left) and 2005 (right).*

Differences between the Uchugrak burned and unburned sides of the fireline observed in 2005 included more *Sphagnum* moss on the unburned side; taller birch shrubs on the burned site (average maximum height = 43 cm) than unburned side (average maximum height = 30 cm); more *Petasites frigidus* on burned than unburned (Table 6); and birch dominant on the unburned but willow slightly dominant on the burned side.

Thaw depths were greater by 10 cm on the burned than on the unburned side of the fireline in 1982 (Table 4), but by 2005 thaw depths were similar (48 cm).

Kugururok (KUGUR-B)

This site is located on a flat plateau above the confluence of the Kugururok and Noatak rivers. There is abundant spruce forest on the slopes below this site down to the rivers (Figs. 16a and b). The site burned in 1972, based on a 1973 satellite image but not recorded in the large fire database (Alaska Fire Service, 2005). However, the site may have burned again in 1984, according to this database. We first sampled the site 10 years after fire in 1982. At that time we established a 60 m long transect from the spruce hill slope up to the flat plateau and then to tussock-shrub tundra. Samples taken from soil pits showed that sand was dominant in the mineral horizon at all three topographic sequences. We were unable to locate the stakes placed in 1982, but from photos and memory we located the 2005 transect very close to the original transect (Figs. 16a and b).

During the past 23 years the vegetation composition has changed while the total vascular cover (80%) remained about the same (Table 7; Fig. 17). In 1982, 10 years after the fire, total grass cover (*Calamagrostis* sp. and *Poa* sp.) was almost 25% and shrub cover was only 17% (predominantly *Salix pulchra*) (Fig. 17). By 2005 grasses were absent and shrub cover had doubled to 36%, with birch dominant (25%) (Table 7). There appears to have been establishment of evergreen shrubs (Labrador tea and lingonberry) and replacement

Table 6. *Frequency (Freq) and average cover (C) for species at Uchugrak unburned and burned sites in 1982 and 2005.*

	Uchugrak unburned				Uchugrak burned			
	1982		2005		1982		2005	
	Freq (%)	C (%)	Freq (%)	C (%)	Freq (%)	C (%)	Freq (%)	C (%)
GRAMINOIDS								
Eriophorum vaginatum	100	13	100	12	100	24	100	27
Carex bigelowii	100	4	100	11	80	6	100	8
Poa sp.	0	0	0	0	20	1	70	0.5
Graminoid cover		17		23		31		35
SHRUBS								
Deciduous shrubs								
Betula nana	100	27	100	22	40	1	90	15
Salix pulchra	100	8	100	5	80	5	100	19
Vaccinium uliginosum	80	4	60	5.1	0	0	0	0
Deciduous Cover		35		27		6		34
Evergreen shrubs								
Ledum palustre	100	7	100	8	60	1	100	2
Vaccinium vitis-idaea	80	7	100	9	40	0.5	90	2
Empetrum nigrum	0	0	20	0.5	0	0	10	0.5
Evergreen cover		14		17.5		1.5		4.5
FORBS								
Saxifraga punctata	40	0.2	10	0.5	60	0.5	20	0.5
Epilobium angustifolium	0	0	0	0	100	3	20	0.5
Petasites frigidus	0	0	60	0.5	0	0	90	6
Pyrola	10	0.2	10	0.2	40	0.2	10	0.5
Rubus chamaemorus	20	0.5	10	0.4	60	1	40	1
Forb cover		1.0		1.6		4.7		8.5
BRYOPHYTES								
Sphagnum sp.	20	1	70	5	0	0	10	0.5
Polytrichum	0	0	30	0.5	10	0.5	50	3
Feather moss	100	20	90	9	0	0	80	1
Aulacomnium sp.	100	20	40	1	0	0	80	1.5
Marchantia polymorpha	0	0	0	0	100	3	0	0
Ceratodon purpureus	0	0	0	0	80	8	0	0
Bryophyte cover		41		15.5		11.5		6
LICHEN								
Peltigera	0	0	60	0.5	0	0	30	0.5
Cetraria cucullata	0	0	40	0.5	0	0	0	0
Lichen cover		0		1		0		0.5

Figure 16a. *Kugururok shrub-tussock tundra site on bench above the confluence of the Noatak and Kugururok Rivers (background) in July 1982, 10 years after a 1972 fire.*

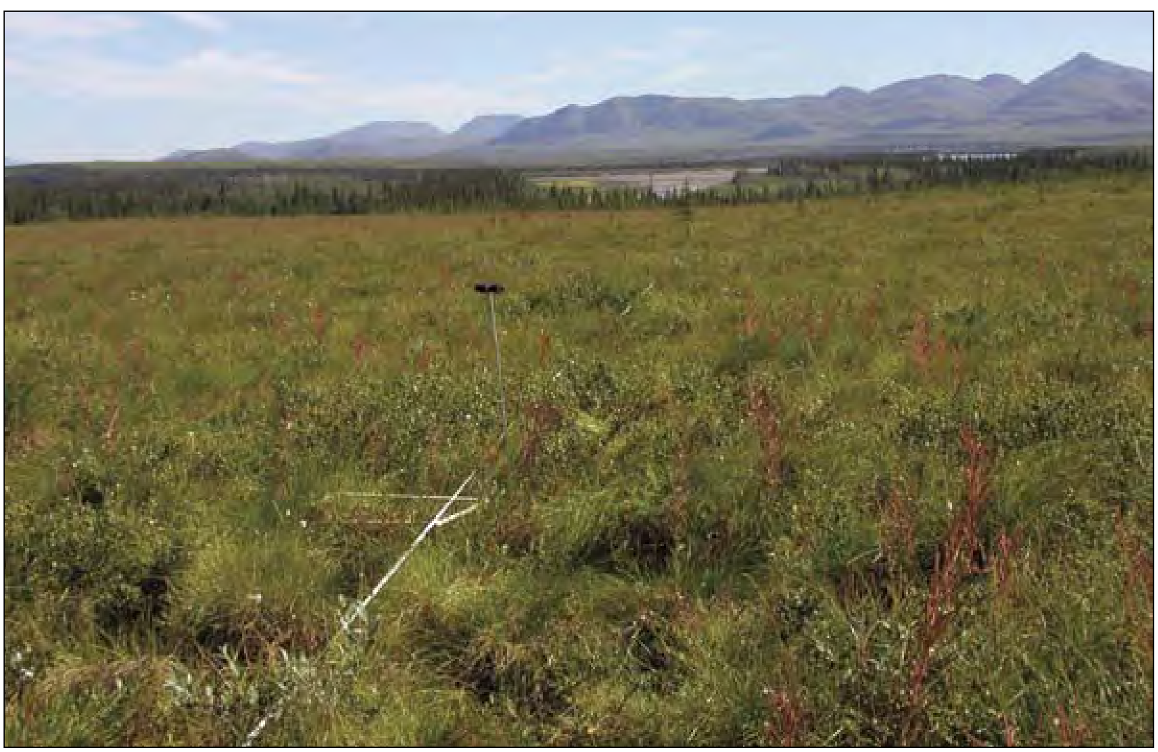

Figure 16b. *Kugururok site in July 2005. Note the dead spruce in 1982 background have fallen by 2005.*

of willow by birch at this site. Thaw depths at this site were almost 20 cm greater than in 1982, a greater difference than at any other site (Table 4). The increase in thaw depth may be due to the high sand fraction in the mineral horizon, making it more susceptible to climate warming, or it may have resulted from the difference in sample dates between 1982 and 2005.

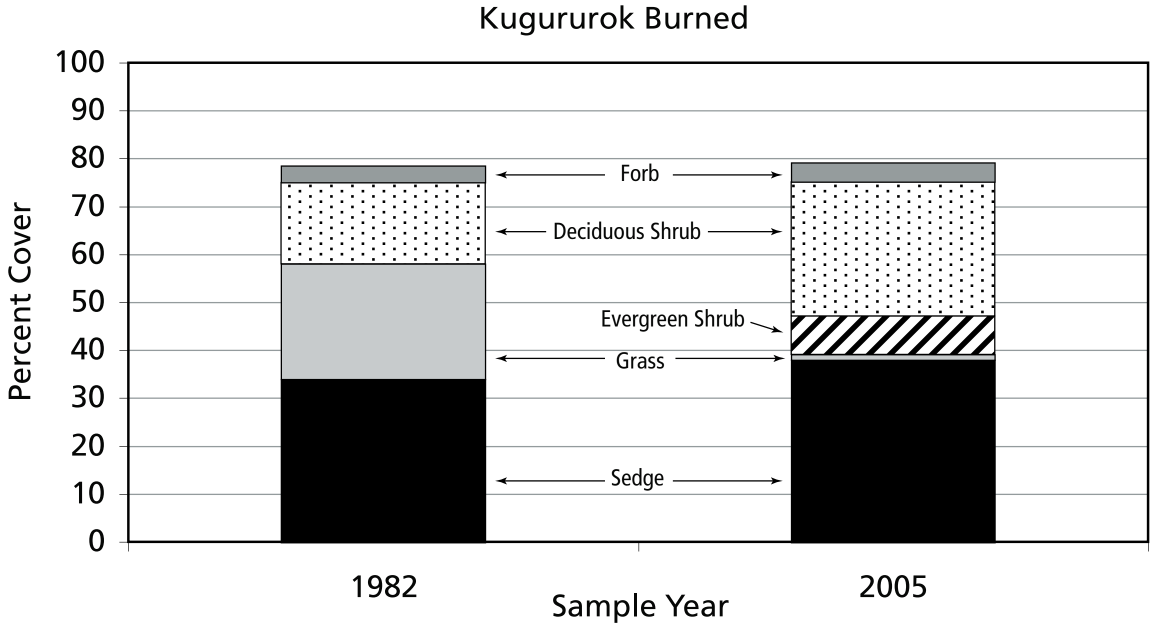

Figure 17. *Average percent cover by growth form at Kugururok 1972 burn site in 1982 (left) and 2005 (right). Note loss of grass cover.*

White spruce forest borders this site along the steep banks down to the Noatak and Kugururok Rivers (Figs. 16a and b). In 2005, a single spruce seedling was sampled in one of the plots, and spruce seedlings were fairly numerous in the tussock-shrub tundra nearby. Eight spruce seedlings were counted in a 60 m x 1 m belt transect established in 2005. Most of the spruce seedlings were growing in the intertussock spaces and ranged in height from 0.2 to 0.5 m, with estimated ages ranging from 8 to 17 years. A comparison of photos taken along the edge of this site in 1982 and in 2005 (Fig. 18a and b) reveals several changes. The standing dead spruce killed by the 1972 fire are visible in the 1982 photo. By 2005 these dead trees are no longer visible and presumably had decayed, blown over, or were possibly consumed by another fire in the intervening 23 years. In addition the visual evidence presented in Fig. 18a and b suggests that shrub birch had largely replaced *Salix pulchra*, a finding that is consistent with the sampling results obtained in the Kugururok plots (Table 7).

Table 7. *Frequency (Freq) and average cover for species at the Kugururok tussock-shrub tundra site, which burned in 1972 and possibly again in 1984.*

	Kugururok			
	1982		2005	
	Freq (%)	C (%)	Freq (%)	C (%)
GRAMINOIDS				
Sedge				
Eriophorum vaginatum	100	21	100	23
Carex bigelowii	100	13	100	15
Sedge cover		34		38
Grass				
Poa sp.	100	3	0	0
Calamagrostis inexpansa	100	20	60	1
Arctagrostis latifolia	70	1	10	0.1
Grass cover		24		1
SHRUBS				
Deciduous shrubs				
Betula nana	10	2	100	25
Salix pulchra	100	15	70	3
Deciduous cover		17		28
Evergreen shrubs				
Ledum palustre	0	0	80	4
Vaccinium vitis-idaea	0	0	70	4
Evergreen cover		0		8
FORBS				
Saxifraga punctata	0	0	30	0.5
Epilobium angustifolium	90	3	60	1
Pyrola	10	0.5	30	2
Rubus chamaemorus	0	0	20	0.2
Forb cover		3.5		4
TREES				
Picea glauca	0	0	10	0.1
BRYOPHYTES				
Polytrichum sp.	30	0.5	20	1
Aulacomnium sp.	60	1	20	0.5
Marchantia polymorpha	40	0.5	0	0
Drepanocladus sp.	0	0	20	0.5
Bryophyte cover		2		2
LICHEN				
Peltigera sp.	10	0.1	90	4

Figure 18a and b. *Edge of Kugururok site in 1982 (above) and 2005 (below). Note large increase in birch shrubs and spruce saplings during the past 23 years.*

Overall Site Changes

We compared the vegetation cover for differences by year for the burned (six sites, n = 60 plots) and unburned sites (two sites, n = 20 plots), using individual plots for variance. Between the two sample times (1981–82 and 2005) we found a significant difference in cover for all growth forms for the burned sites except for forbs (Table 8). Overall there was an increase in total vascular plant cover as sites aged post fire, with a significant increase in both deciduous and evergreen shrubs and sedges over time. We detected a significant decrease in average grass cover, and, while not significant, forb cover was slightly higher 23–33 years post-fire than 1–10 years post-fire. On the unburned control sites, only grass cover was significantly different between the sample years, with a slight increase over time (0.2%) (Table 9). Although not significant, there were trends for a decrease in sedge cover and an increase in shrub cover on the unburned plots.

Table 8. *Kruskal-Wallis test of significance for difference in growth form cover between sample years for burned plots at Noatak. Average percent cover and standard deviation (SD) by growth form for each sample year.*

Growth form	χ^2	df	Asymp. significance	Average % cover 1981–82	SD	Average % cover 2005	SD
Deciduous shrub cover	31.7	1	0.000	13.3	12.5	33.8	22.5
Evergreen shrub cover	26.2	1	0.000	0.9	1.8	11.3	17.3
Grass cover	65.6	1	0.000	8.5	9.3	0.7	1.9
Sedge cover	7.7	1	0.003	20.5	18.7	32.5	26.2
Forb cover	0.15	1	0.696	5.8	4.7	7.1	7.7
Total vascular cover	44.4	1	0.000	49.2	22.5	85.3	25.8

Table 9. *Kruskal-Wallis test of significance for difference in growth form cover between sample years for unburned plots at Noatak. Average percent cover and standard deviation (SD) by growth form for each sample year.*

Growth form	χ^2	df	Asymp. significance	Average % cover 1981–82	SD	Average % cover 2005	SD
Deciduous shrub cover	3.0	1	0.083	19.4	16.9	28.0	14.1
Evergreen shrub cover	2.06	1	0.151	16.2	8.8	23.2	12.3
Grass cover	4.23	1	0.040	0.0	-	0.2	0.3
Sedge cover	3.01	1	0.083	37.8	17.9	28.0	13.1
Forb cover	3.1	1	0.078	0.2	0.3	0.8	1.1
Total vascular cover	1.69	1	0.194	73.5	11.9	80.1	14.8

DISCUSSION

The regrowth following fire during the past 23 years (1982–2005) varied at the six burn sites sampled. However, several main vegetation response trends were detected, including (1) an increase in vascular plant cover at all sites burned in 1977 or 1982 but not at the site burned in 1972, (2) near extirpation by 2005 of the grasses (primarily *Calamagrostis* sp. and *Poa* sp.) that were common at most sites in 1981–82, four to five years after fire, (3) a decline in the number of forb species present at two of three high-species-diversity shrub tundra sites, and (4) a pronounced increase in shrub cover at all burned sites.

Vascular plant cover increased from 1982 to 2005 at all five sites burned in 1977 or 1982 but not at a site burned in 1972 (Table 10). Fire-adapted sedge (*Eriophorum vaginatum*) tussocks recover quickly from unburned live stem bases and account for most of the early vascular cover increase during the first four to five years after fire in tussock-shrub tundra. The only site where we found a sizeable increase in sedge cover over the past 23 years was a tussock-shrub tundra site burned in 1982 (Kungiakrok) and sampled a few weeks after fire. Although *E. vaginatum* sedge seedlings became established within a few weeks after fire at this site, few or none of these survived to establish new tussocks.

Grasses may also expand during this early stage of recovery, particularly in burned shrub tundra. In 1982 grass cover was 20–30% at Kugururok and NOAT 1 sites but virtually absent 23 years later. This grass phase is common in shrub tundra (Racine et al. 1987) but not in tussock-shrub tundra, although we found *Calamagrostis* sp. cover of 20% 10 years after fire at the Kugururok tussock-shrub tundra site with sandy soils (Fig. 17). Forb species richness also appears to have decreased, particularly at the shrub tundra sites, which contained large numbers of forb species four to five years after fire. Overall forb cover increased slightly, but at most sites this was due to increased cover in horsetail (*Equisetum*).

The most notable change in vascular cover during the subsequent 23 years was due to an expansion of shrubs. Shrub cover doubled at all burned sites (Table 8), while the two unburned sites had a smaller increase in shrub cover. Deciduous shrubs, most commonly birch, accounted for most of the shrub increase at all sites (Table 11). At all sites except for Kugururok, the same species of shrub dominant in 1981–82 was still dominant in 2005 (Table 11). At the Kugururok tussock-shrub site, willow was dominant in 1982, but by 2005 birch was dominant. On the edge of this site (Fig. 18a and b) paired photos also suggest replacement of willow by birch. At Uchugrak willow was dominant on the burned site but birch was dominant on the unburned, suggesting longer-term replacement of willow by birch. The trend of increasing birch due to its ability to outcompete other tundra shrub species is predicted by experimental studies (Bret-Harte et al. 2001). At NOAT 1 both evergreen and deciduous shrubs each increased about 30%, but birch was significantly taller than Labrador tea, suggesting that birch might replace Labrador tea here over time.

Studies using repeat photos of an area of the Noatak near the tundra fire sites we monitored have detected an increase in both alder shrubs and spruce (Sturm et al. 2001; Tape et al. 2006). In the present study both spruce and alder occurred in fairly close proximity to our study sites. In 2005, we found at least two spruce seedlings in plots where none were sampled in 1981–82, but we did not find alder in any plot.

Table 10. *Summary of change in cover of growth forms for burned and unburned control sites sampled during 1981–82 and 2005.*

	% change in cover			
Site (Fire date)	**Vascular plants**	**Graminoids**	**Deciduous shrubs**	**Evergreen shrubs**
Tussock-shrub				
NOAT 3 (1977)	+14%	+<10%	+18%	nc
KUNG-B (1982)	+51%	+35% (sedge)	+10%	+11%
KUNG-U	+10%	−15% (sedge)	+15%	+11%
UCHG-B (1977)	+39%	+4% (sedge)	+28%	nc
UCHG-U	nc	+6% (sedge)	−8%	nc
KUGUR-B (1972)	nc	-23% (grass)	+11%	+8%
Shrub Tundra				
NOAT 1 (1977)	+37%	+6% (sedge)	+35%	+30%
		−30% (grass)		
NOAT 2 (1977)	+30%	+10% (sedge)	+10%	nc
		−6% (grass)		

Table 11. *Summary of dominant and subdominant shrub species and cover at each site in 1981–82 and 2005.*

	1981–82		2005		2005	
Site (Fire year)	**Dominant shrub**	**(% cover)**	**Dominant shrub**	**(% cover)**	**Next dom. shrub**	**(% cover)**
Tussock-shrub						
KUNG-B (1982)	*Betula nana*	3	*B. nana*	10	*Ledum palustre*	10
KUNG-U	*L. palustre*	18	*L. palustre*	26	*B. nana*	18
UCHG-B (1977)	*Salix pulchra*	5	*S. pulchra*	19	*B. nana*	15
UCHG-U	*B. nana*	27	*B. nana*	22	*L. palustre*	8
KUGUR-B (1972)	*S. pulchra*	15	*B. nana*	25	*L. palustre*	4
NOAT 3 (1977)	*S. glauca*	16	*S. glauca*	20	*S. reticulata*	11
Shrub tundra						
NOAT 1 (1977)	*Bet-Vac-Ledum*	9	*L. palustre*	33	*B. nana*	24
NOAT 2 (1977)	*V. uliginosum*	2	*V. uliginosum*	14	*S. arctica*	6

Experiments and remote sensing suggest that the response of arctic tundra vegetation to increased nutrients and warmer soils results in an increase in deciduous shrubs, decreased plant diversity, and loss of lichens (Chapin et al. 1995, 1996; Sturm et al. 2001; Stow et al. 2004, Hollister et al. 2005; Tape et al. 2006). Such changes in plant functional types (increased deciduous shrub abundance and size) are important to the surface energy balance (summer sensible heat flux), carbon balance (increased carbon storage in wood), forage for herbivores, and winter snow depth (deeper snow due to shrubs trapping blowing snow) (Sturm et al. 2005).

Some of the long-term vegetation change we observed on burned tussock tundra sites could have been due to climate warming, which is predicted to result in the expansion of deciduous shrubs, particularly birch (Bret-Harte et al. 2001), in tussock-shrub tundra (Shaver et al. 2001). Our two unburned plots should show this influence if it is being exerted in our study area; we found an increase in shrubs and birch at one site (Kungiakrok) but a small decrease in shrubs and birch at the other (Uchugrak Hills) (Table 10). Some of the ecosystem changes produced by wildfire are similar to those predicted for climate warming, including warmer soils and accelerated rates of decomposition and nutrient release, earlier snowmelt, etc. It therefore becomes difficult to separate the effects of climate warming which has been observed in arctic Alaska during the term of this study (1977–2005), from the effects of fire, but it is possible that the effects of fire have accelerated the changes expected from climate warming.

Comparisons With Vegetation Recovery at Other Tundra Fire Sites

Comparisons of post-fire vegetation recovery at the Noatak sites can be made with Nimrod Hill in Bering Land Bridge National Preserve, a series of eight sites from the bottom to top of a hillslope on the Seward Peninsula that burned in 1977, which we sampled at several intervals between 1978 and 2001 (Racine 1981; Racine et al. 2004). At Nimrod Hill we also found a large increase in shrubs: 6–10% cover in 1980 increasing to 40–50% by 2001. This shrub cover change is similar to that observed at the Noatak sites. At Nimrod Hill, however, the shrub increase was due mainly to evergreen shrubs (Labrador tea) on the poorly drained tussock-shrub tundra flats at the foot of the hill and to deciduous shrubs (willow rather than birch) on the better-drained portions of the hillslope. The Kungiakrok site in the Noatak is also located on poorly drained flats and shows a similar predominance of Labrador tea. In the Noatak, birch played a much more important role in post-fire shrub recovery than it did on Nimrod Hill, where it was present but low in cover at all sites.

Monitoring Recommendations

The objectives of the NPS Inventory and Monitoring Program include providing for long-term monitoring of vegetation and park ecosystems to better understand their dynamic nature and condition and to provide reference points for comparisons with other, altered environments. Permanent plots that are revisited over time provide the most accurate opportunity to detect change. While our plots were not originally established with the purpose of monitoring recovery beyond the two years of the study, our ability to find and resample them suggests they may be useful to the NPS Inventory and Monitoring Program for long-term monitoring of response to fire.

Resampling old photo sites may offer the ability to detect changes in larger trees and shrubs (Sturm et al. 2001), or using spectral reflectance from satellite imagery may be useful for detecting broad vegetation change over large areas. Quantitatively sampled plots are greatly preferred for tundra areas with low vegetation. Revisiting the same plots removes plot-to-plot differences from the change estimates, permitting better precision. When repeated measurements of the same site are made over time to determine trends, the precision will increase as the number of years sampled increases, making assured relocation and sampling of old plots particularly valuable. The challenge in resampling fixed plots is in distributing enough of them across the landscape to adequately represent the landscape.

Accurate, durable marking allowing the ability to relocate and resample plots exactly on the ground is critically important in the use of fixed plots. Clearly rebar or other metal stakes and GPS are the most effective tools, but in remote areas transporting heavy materials may be too expensive. We found in this study that a majority of small (short) wooden stakes or stems made on site from shrub (alder and willow stems) survived at plot corners for 23 years. By replacing the small stakes with new wooden stakes after 23 years, we sought to ensure that the plots could be relocated for another 23 or more years. Such periodic renewal of the marking devices is also an important part of maintaining permanent plots for long-term monitoring.

It is also important if possible that the same personnel who originally established and sampled the plots relocate and resample them, particularly when GPS coordinates are not available. At the same time, it is important to have new investigators accompany the old investigators into the field to ensure effective handing off of the plots to the next generation of field monitorers.

The ability to detect trends or change in vegetation also depends on how often plots are resampled and the method used. The Noatak plots described here were sampled only once or twice (1981–82). In Bering Land Bridge National Preserve, Imuruk Lake plots were sampled at least five times during the past 23 years. Depending on the sampling method, it is also desirable to have experienced personnel resample the plots. Because ocular cover estimates in 1 m x 1 m plots were used here, it is important that samplers be experienced. Perhaps a change to gridded point intercept-sampled plots would be desirable, although this may reduce the ability to pick up rare or infrequent species. Daubenmire-style sampling and cover estimates by class should be avoided.

It is also important to know the disturbance history of long-term monitoring sites. Change most often occurs following a disturbance such as fire, but climate warming without any surface disturbance is also expected to cause change. Therefore monitoring should include paired control (undisturbed) sites to separate the change due to disturbance from that due to warming.

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